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# **The Effects of Degraded Visual Cueing and Divided Attention on Obstruction Avoidance in Rotorcraft**

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16. Abstract The FAA is investigating rotorcraft obstruction related accidents. This report is a small part of that effort. It is based on analysis, ground-based simulation, and flight testing conducted in support of the U.S. Army rotorcraft flying qualities specification. Portions of that work involved the evaluation of rotorcraft flying qualities in degraded visual environments. These tests showed that a deterioration in the effective rotorcraft flying qualities occurred in conditions of degraded (but not zero) visual cueing. In such flight conditions, the pilot workload was very high, just for aircraft control. This left the pilot very little excess workload capacity to maintain awareness of the rotorcraft position and rates with respect to obstructions or the ground. This indicates that the combined effects of a degraded visual environment, turbulence, and only fair basic rotorcraft handling can lead to a workload that exceeds the pilot's capability. This leads to a loss of situational awareness and it explains many accidents where experienced pilots have committed seemingly absurd errors. For example, pilots drifted into objects in their field-of-view, inadvertently transitioned into rearward or sideward flight, and flew into the ground. Army experiments indicate that the addition of artificial stabilization can substantially improve flying qualities in degraded visual environments. This results in a dramatic decrease in the attentional demand required for rotorcraft control and more capacity to maintain situational awareness. Thus increased stabilization may have a more positive impact on decreasing collision avoidance accidents in degraded visual environments than many more intuitively obvious solutions (e.g., cockpit warning lights, horns, etc.).					
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## EXECUTIVE SUMMARY

The Federal Aviation Administration has undertaken an effort to investigate obstruction-related accidents during civil rotorcraft operations. The overall project is termed "Rotorcraft Obstruction Avoidance, Task 8A". This report represents an element of that effort. It is based on analysis, ground-based simulation, and flight-testing conducted in support of the U.S. Army rotorcraft flying qualities specification. A significant portion of that work consisted of the evaluation of rotorcraft flying qualities in degraded visual environments. These tests showed that a deterioration in the effective rotorcraft flying qualities occurred in conditions of degraded (but not zero) visual cueing. The pilot workload in such flight conditions was observed to be very high, just for aircraft control. This left the pilot with very little excess workload capacity to maintain an awareness of the rotorcraft position and rates with respect to obstructions or the ground (termed "situational awareness" in this report). The workload for rotorcraft control in conditions of degraded visual cueing is quantified through the use of results of previous human factors experiments. These results indicate that the combined effects of a degraded visual environment, turbulence, and only fair basic rotorcraft handling, can easily lead to a workload that is 100% of the pilot's capability. This situation is highly conducive to substantial loss of situational awareness. This loss of situational awareness is used to explain many of the accidents included in the National Transportation Safety Board (NTSB) data-base, where experienced pilots are seen to have committed seemingly absurd errors. For example, pilots drifted into objects in their field-of-view, inadvertently transitioned into rearward or sideward flight, and flew into the ground. The Army experiments noted above indicated that the addition of artificial stabilization provides a substantial improvement in flying qualities in degraded visual environments. This results in a dramatic decrease in the attentional demand required for rotorcraft control, and therefore more capacity to maintain the required situational awareness. In summary, this report concludes that increased stabilization may have a more positive impact on decreasing collision avoidance accidents in degraded visual environments than many more intuitively obvious solutions (e.g., cockpit warning lights, horns, etc.).

## INTRODUCTION AND BACKGROUND

The work reported herein represents a small component of a much larger effort (References 1 and 2) to investigate the fundamental reasons for rotorcraft accidents involving collisions with obstructions. Many of these accidents have occurred while operating in difficult visual conditions such as in rain, haze, fog, snow, over water, and/or at night. There is growing interest in using vision aids (e.g., night vision goggles, FLIR, millimeter wave radar) to improve the safety of operations in difficult visual conditions. This is an important step in the right direction. However, testing conducted in support of the military flying qualities specification for rotorcraft has shown that, under some critical conditions (e.g., overcast night with night vision goggles, cold soak with FLIR, etc.), vision aids do not reproduce adequate microtexture to accomplish low speed and hover operations at a safe level of pilot workload. Rotorcraft operations in conditions of degraded visual cueing have been studied extensively by the military, and the results of that work apply equally to flight with and without vision aids. One purpose of this report is to interpret those results in a way that is applicable to civilian operations.

It is well known that flight in IMC conditions without the proper instrumentation and training, is almost certain to result in loss of control. The controllability of rotorcraft in conditions of degraded (but not zero) visibility is less well understood. This problem was addressed in the recent military helicopter specification revision (Reference 3) by developing more appropriate descriptors of the visual conditions. Today, visual conditions for civil operations are defined as either instrument or visual meteorological conditions (IMC or VMC). The physical significance of these definitions relates to whether the pilot is controlling the aircraft with respect to cues that are primarily inside or outside the aircraft. The military specification includes a Usable Cue Environment (UCE) scale that is specifically intended to apply to operations conducted close to the ground or water, and with respect to objects outside the cockpit (discussed in Section 3). The Reference 3 specification refers to operations conducted close to the ground or water (or a ship) in poor visibility as being conducted in a "degraded visual environment" or DVE. The term DVE is also used in this report to be consistent with previous work. The connection between the UCE and obstruction avoidance lies in the critical nature of rotorcraft controllability and its effect on pilot workload when operating in near proximity to obstructions. For example, in hover, a change in pitch or roll attitude of only 1 degree results in a linear displacement of approximately 14 feet in 5 seconds; enough to cause a collision with an obstacle in a confined area. This is contrasted with IMC where the precision of control is significantly less critical as a result of the much larger areas of protected airspace that surround the aircraft.

The basic premise of the present study is that a significant number of collisions with obstructions result from periods of inadequate "situational awareness" in degraded visual environments. Here, situational awareness refers to an awareness of aircraft attitude, translational rate, altitude above the ground, vertical rate, and position with respect to obstructions. The assertion is that reduced situational awareness results when the pilot workload becomes excessive, and that excessive workload tends to occur in degraded visual environments. The connection between excessive workload and the DVE arises from experimental observations, which indicate that degraded visual cueing has the same effect as degrading the rotorcraft flying qualities. These observations are a result of in-flight and ground-based simulation data, which are discussed in detail in Section 3. There, it is shown that a primary cue required to stabilize the rotorcraft in hover and low speed flight is the "microtexture" in the pilot's near field-of-view (e.g., individual blades of grass, small

stones, etc.). This cue tends to be obscured in certain conditions (e.g., over snow or water, at night, etc.), even though most objects in the field-of-view can be seen clearly.

Estimates developed in Section 4 indicate that hovering an unaugmented helicopter in a degraded visual environment consumes at least 70% of the pilot's available workload capacity. This leaves only 30% to maintain an adequate level of situational awareness. Any factors that require "division of attention" away from the aircraft control task further detract from the time spent clearing the area around the helicopter. Finally, turbulence and strong winds add a significant increment to the already high pilot workload. Factors related to division of attention, turbulence, and lack of situational awareness are called out in the accident narratives that follow in Section 2.

The risk of collision avoidance in degraded visual environments is somewhat dependent on pilot training and background. This is a direct consequence of the fact that the workload required for aircraft control is higher for the less trained or less current pilot, or for a pilot with little experience in operating in degraded visual environments. The method developed in Section 4 implicitly accounts for variations in pilot skill level.

Variable stability flight testing and ground based simulation has shown that increased stabilization is an effective measure to improve rotorcraft flying qualities in a degraded visual environment. The procedure to quantify the visual environment is highly structured in the military flying qualities specification (Reference 3) and results in a requirement for specific levels of stabilization or "Response-Types." It is not deemed practical to invoke such stringent requirements for civilian aircraft. The context of the present work is to interpret these military requirements and supporting data in terms of civilian operating scenarios. Such interpretations are expected to:

- provide a better understanding of the root cause of some obstruction avoidance accidents.
- provide a better appreciation of the role of stabilization as a potential avenue for improving safety for operations in degraded visual environments.
- provide a better understanding of components of pilot workload when operating in a degraded visual environment.

In summary, this report provides evidence to support the following assertions.

- Operations in a degraded visual environment result in a deterioration in the rotorcraft flying qualities<sup>1</sup>
- Degraded flying qualities result in increased pilot workload for aircraft control, and therefore less time to spend on situational awareness (which is strongly related to obstruction avoidance).
- Increased stabilization restores some of the flying qualities lost due to the DVE, resulting in decreased pilot workload for aircraft control. As a result, the pilot has more workload capacity to maintain an adequate level of situational awareness.

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<sup>1</sup> As used in this report, the term "flying qualities" refers to the rotorcraft controllability in a specified environment. The term "basic flying qualities" refers to rotorcraft controllability in ideal environmental conditions, e.g., good visibility and no turbulence. The terms "flying" and "handling" qualities are used interchangeably in this report.



This evidence has been developed through the following efforts.

- An examination of all the rotorcraft accidents from 1982 thru 1987 was conducted using NTSB data stored on high density floppy disks. All the accidents that involved collisions with obstructions (including the ground or water), a potentially degraded visual environment, and/or pilot division of attention were analyzed in the context of the above arguments. These results are presented in Section 2.
- The analyses and data supporting the requirements for DVE operations in the Reference 3 military flying qualities specification was reviewed in the context of civilian operating scenarios. This is presented in Section 3.
- The results of flight testing and ground-based simulation conducted in support of the military flying qualities specification were combined with known analysis techniques for quantifying pilot workload. High values of pilot workload required for rotorcraft control are interpreted to mean decreased situational awareness, and therefore an increased vulnerability to collision with obstructions. This concept is developed and quantified in Section 4.

The conclusions reached from this study are presented in Section 5.

## II SELECTED ACCIDENT BRIEFS INVOLVING DEGRADED VISUAL ENVIRONMENTS AND DIVIDED PILOT ATTENTION

The following accident briefs are presented as examples where combinations of degraded visual environments (DVEs), divided pilot attention, and atmospheric disturbances were clearly factors. These factors are emphasized in the right column. The underlined heading for each accident brief is the NTSB reference number.

### **SELECTED NTSB ACCIDENT BRIEF DATA INVOLVING POOR VISUAL CUING OR DIVIDED ATTENTION AS A FACTOR - 1982 THRU 1987**

#### **ANC82DA027 1820725820809**

WHILE FLYING AT APPROXIMATELY 300 FEET AGL IN WINDY TURBULENT CONDITIONS OVER SNOW COVERED TERRAIN, THE HELICOPTER IMPACTED THE FROZEN RIVER. AT THE TIME OF THE ACCIDENT THE PILOT WAS CHANGING RADIO FREQUENCIES WHEN IMPACT OCCURRED.

#### **ATL82DA258 830124830622**

THE PILOT RECEIVED A WEATHER BRIEFING BEFORE TAKING OFF ON AN AERIAL TRAFFIC PATROL FOR A LOCAL RADIO STATION. HE WAS ISSUED A SPECIAL VFR CLEARANCE TO FOLLOW A PRE-ESTABLISHED ROUTE. HOWEVER, AFTER DEPARTING, HE ENCOUNTERED THUNDERSTORM ACTIVITY. HE RETURNED TO THE DEPARTURE AIRPORT AND HOVERED UNTIL THE THUNDERSTORM ACTIVITY SUBSIDED. AFTER ABOUT 30 MINUTES, THE PILOT DEPARTED AGAIN, BUT WAS UNABLE TO CONDUCT THE FLIGHT AS PLANNED. WITH THE WEATHER DETERIORATING, HE RECEIVED CLEARANCE TO ANOTHER AIRPORT. WHEN HE WAS ABOUT ONE MILE FROM THE AIRPORT, THE VISIBILITY WAS REPORTED AS 1/2 MILE. HE REPORTED THAT WHEN HE WAS ABOUT 100 FT AGL, HE TURNED NORTHEAST INTO THE WIND TO GET CLOSE TO THE BOUNDARY ROAD AND FENCE AND TO GET VISUAL REFERENCES. ALSO, HE STATED THAT THE VISIBILITY THROUGH THE BUBBLE WAS DISTORTED BY THE HEAVY DOWNPOUR AND BUBBLE FOG. WHILE ATTEMPTING A HOVERLANDING, HE TOUCHED DOWN, TAIL LOW, MOVING REARWARD. THE REAR PART OF THE SKIDS AND THE TAIL ROTOR HIT THE GROUND AND CONTROL WAS LOST.

#### **DEN83LA043 830408830728**

PILOT TRIED TO LAND AT 12,500 FOOT LEVEL. IN THE ROTORWASH WHITEOUT HE LOST VISUAL CUES AND ROTOR STRUCK THE SLOPE BECAUSE THE RIGHT LANDING GEAR MADE SNOW CONTACT.

#### **DEN82DA131 821126830819**

THE PILOT STATED THAT DURING LIFT-OFF HE WAS DISTRACTED BY PERSONS ON THE GROUND WAVING THEIR ARMS. THE AIRCRAFT DRIFTED TO THE LEFT AND CONTACTED A TREE AFTER WHICH THE PILOT LANDED THE AIRCRAFT AND IT ROLLED OVER.

### **FACTORS RELATED TO VISUAL ENVIRONMENT AND DIVIDED ATTENTION**

- Vertical rate cues were degraded due to lack of microtexture over snow covered river.
- Divided attention due to winds and turbulence, and to tuning radio.
- Loss of situational awareness was manifested as an undetected descent into the terrain.

- Inadequate translational rate cues due to degraded visual cuing.
- Considerable division of attention due to thunderstorm and inability to complete assigned mission.
- Situational awareness lost due to excessive pilot workload.

- Poor visual cuing contributed to undetected sink-rate and lateral drift.
- Division of attention due to mountainous terrain and limited performance due to altitude.

- Significant Division of attention away from aircraft control

DEN82DA022 821123830418

AFTER A PRECAUTIONARY LANDING ON A ROAD DUE TO SNOW, WIND, AND REDUCED VISIBILITY, THE PILOT TOOK OFF WHEN HE DECIDED CONDITIONS HAD IMPROVED. SHORTLY AFTER TAKEOFF THE VISIBILITY WORSENER AND DURING THE EXECUTION OF A 180 DEGREE TURN THE PILOT STATED THE ENGINE LOST POWER. WITH THE ALTITUDE TOO LOW FOR AUTOROTATION, THE PILOT LANDED STRAIGHT AHEAD. DURING THE LANDING A SKID BROKE AND THE AIRCRAFT ROLLED OVER. NO PREIMPACT MALFUNCTION OR FAILURE OF THE AIRCRAFT'S ENGINE WERE DETERMINED DURING THE SUBSEQUENT INVESTIGATION.

850423850423ANC83FA032 MLB

THE HELICOPTER WAS ON A RESCUE/RECOVERY FLIGHT FOR THE ALASKA STATE TROOPERS WITH THE PILOT & A STATE TROOPER ON BOARD. THEY DEPARTED IN VARIABLE WEATHER CONDITIONS TO RESCUE THE PILOT OF ANOTHER AIRCRAFT. REPORTEDLY, SNOW WAS FALLING IN THE SEARCH AREA & THE WINDS WERE GUSTING BETWEEN 70 & 90 MPH. ACCORDING TO THE PILOT, THE ENGINE FLAMED OUT DURING A TURN AT APPROXIMATELY 1000 FT AGL. HE BEGAN AN AUTOROTATION & TRANSMITTED A DISTRESS CALL. DURING AN APPROACH TO A FROZEN RIVER, HE ENCOUNTERED A TOTAL WHITEOUT CONDITION IN FOG & BLOWING SNOW AT APPROXIMATELY 75 TO 100 FT AGL. HE GUESSED AT THE ALTITUDE TO APPLY COLLECTIVE PITCH TO STOP THE DESCENT & SAID THAT HE EXPERIENCED VERTIGO DURING THE LAST PART OF THE DESCENT. THE AIRCRAFT IMPACTED IN A LEFT, NOSE DOWN ATTITUDE & ROLLED OVER. THE OCCUPANTS WERE UNABLE TO REACH THEIR SURVIVAL GEAR IN THE WRECKAGE. WEATHER DELAYED THEIR RESCUE & THE PASSENGER DIED FROM HYPOTHERMIA. THE AIRCRAFT WAS EQUIPPED WITH PARTICLE SEPARATORS, BUT NO SNOW DEFLECTORS WERE INSTALLED. NO MECHANICAL ENGINE FAILURE WAS FOUND, BUT A COATING OF ICE WAS FOUND IN THE ENGINE INLET.

850423850423ANC83FA066 DVT

THE PILOT WAS ON AN EXTERNAL LOAD OPERATION WITH A 100 FT LONG LINE. THE LONG LINE HAD 4 REMOTE HOOKS, OF WHICH, 3 HAD CABLE BAGS ATTACHED. WHILE WAITING FOR THE 4TH BAG TO BE FILLED, HE DECIDED TO LAND IN AN OPEN AREA. HE SET THE EXTERNAL LOAD DOWN & LAID THE LONG LINE OUT OVER THE GROUND, "LANDING THE HELICOPTER WHEN THE LONG LINE WAS NEARLY EXTENDED AWAY FROM THE LOAD." WHEN THE 4TH BAG WAS READY TO BE SLUNG OUT, HE LIFTED OFF IN WINDS THAT WERE GUSTING TO 15 KTS. AT A HEIGHT OF ABOUT 40 FT, HE MADE A LEFT, RUDDER TURN (X-WIND) TO BETTER OBSERVE HIS LONG LINE. HE REALIZED THAT HE WAS DRIFTING DOWNWIND AT ABOUT THE TIME HE THOUGHT HE DETECTED A POWER SURGE. HE DIRECTED HIS ATTENTION TO THE ENGINE INSTRUMENTS. AT ABOUT THE SAME TIME, THE HELICOPTER ROLLED ON ITS LEFT SIDE & CRASHED. AN EXAMINATION OF THE WRECKAGE WAS MADE, BUT NO MECHANICAL PART FAILURE/MALFUNCTION WAS FOUND.

- The conditions were highly conducive to a degraded visual environment.
- Significant division of attention due to poor weather and high winds.
- The accident may have been a result of an inadvertent touchdown caused by a lack of situational awareness (nothing was found to be wrong with the engine).

- Extreme case of divided attention workload which exceeded the ability of the pilot to control the rotorcraft. This included extremely high winds with corresponding turbulence, poor attitude and translational rate cues, and an engine failure. Any one of these factors would result in a workload of nearly 100%.
- A stabilized platform would have resulted in significant workload reduction by minimizing the aircraft response to turbulence, and by maintaining a level attitude during the autorotation.

- Significant division of attention due to sling load, gusty winds, and a perceived engine power surge.
- High workload resulted in less than adequate situational awareness, resulting in inadvertent ground contact.

**850423850423ANC83FA092 DVT**

THE HELICOPTER EXPERIENCED A TAIL ROTOR STRIKE DURING A HARD LANDING WITH A DOOR OPEN. ACCORDING TO THE STUDENT PILOT WHO IS A COMMERCIAL PILOT WORKING ON AN ADD-ON HELICOPTER RATING, THE LEFT COCKPIT DOOR UNLATCHED AND PARTIALLY OPENED ON THE DOWNWIND LEG FOR TOUCH-AND-GO PRACTICE LANDING. SHE CONTINUED THE PATTERN AND FINAL APPROACH WITH THE DOOR UNLATCHED WITHOUT FURTHER INCIDENT. SHE EXPECTED THE DOOR TO FULLY OPEN JUST PRIOR TO TOUCHDOWN WHICH IT DID. AS THE DOOR OPENED SHE APPLIED AFT CYCLIC AND FELT THE SKIDS TOUCH DOWN HARDER THAN NORMAL. THE HELICOPTER SLID FORWARD A SHORT DISTANCE WHILE REMAINING ALIGNED WITH THE RUNWAY. WHEN THE AIRCRAFT STOPPED THE PILOT LOOKED OUT AND NOTICED THE TAIL ROTOR HAD SEPARATED FROM THE HELICOPTER. INSPECTION OF THE DOOR LATCH SHOWED A WORN LATCH ASSEMBLY WHICH WAS DIFFICULT TO CLOSE PROPERLY. INSPECTION OF THE RUNWAY SURFACE REVEALED A TAILROTOR/GUARD STRIKE PRIOR TO AIRCRAFT'S MAIN SKIDS TOUCHING THE GROUND.

- Division of attention due to unlatched door.
- Illustrates that attentional workload demands are more severe for pilots with low time in a given type of aircraft.

**870417870417ANC83LA029 MLB**

THE HELICOPTER MADE A HARD LANDING AT NIGHT AT AN UNLIGHTED DRILL RIG SITE. THE PILOT CALLED THE RIG SITE ON THE RADIO TO ASK FOR LIGHTS BUT THEY WERE NOT TURNED ON. THE PILOT TRIED TO LAND WITHOUT THE LIGHTS AND ENCOUNTERED BLOWING SNOW FROM THE ROTOR WASH. THE ALTITUDE WAS MISJUDGED AND THE AIRCRAFT HIT HARD AND MOVING FASTER THAN EXPECTED. THE PILOT STATED THAT THE ACCIDENT COULD HAVE BEEN AVOIDED IF HE HAD WAITED FOR THE LIGHTS TO BE TURNED ON.

- Degraded vertical rate and horizontal translational rate cues due to darkness and blowing snow.
- Pilot apparently thought cues were adequate; indicates subtle nature of degraded visual cuing.

**850423850423ANC83LA076 DVT**

THE HELICOPTER SKID CONTACTED THE GROUND DURING A HOVERING TURN FOR LANDING AND ROLLED THE HELICOPTER OVER ON ITS RIGHT SIDE. THE PILOT HAD MADE AN APPROACH FOR LANDING TO A 10 FOOT HOVER AND THEN LOST SIGHT OF HIS REFERENCE POINT IN FRESH SNOW PICKED UP BY THE ROTOR SYSTEM. HE TURNED THE AIRCRAFT TO GET A NEW REFERENCE POINT. DURING THE TURN, HE STATED THAT HE LOST ALTITUDE AND NOTICED THE AIRCRAFT MOVING SIDEWAYS AND REARWARD. THEN BEFORE HE COULD CORRECT IN TIME, HE FELT THE RIGHT SKID MAKE CONTACT WITH SOMETHING AND THE HELICOPTER ROLLED OVER.

- Degraded vertical rate and horizontal translational rate cues due to fresh snow which was blown up by the rotor system.
- Pilot did not feel sense of urgency to pull up and away from the terrain - another example of the subtle nature of degraded visual cuing.

**850423850423ANC83LA091 DVT**

THE HELICOPTER COLLIDED WITH A POLE AND LANDED HARD DURING AIR TAXI TO POSITION THE AIRCRAFT. THE PILOT HAD JUST OFF LOADED PASSENGERS AND WAS ALONE IN THE HELICOPTER. A WITNESS SAID THE PILOT HOVERED TOO CLOSE TO THE POLE AND BOTH ROTOR BLADES MADE CONTACT. THE POLE THAT WAS STRUCK WAS SEVERED ABOUT 12 FT AGL.

- Pilot apparently did not notice translational drift, either due to division of attention, or degraded visual cuing, or a combination of the two. Clear case of degraded situational awareness.

**850809850809ANC84FA008 DVT**

ACCORDING TO THE PILOT, HE TOOK OFF UPSLOPE INTO THE WIND IN AN EASTERLY DIRECTION. IMMEDIATELY AFTER TAKING OFF, HE MADE A RIGHT TURN TO A X-WIND, & SECONDS LATER, HE MADE A FURTHER TURN THE RIGHT (DOWNWIND). VISIBILITY TOWARD THE EAST WAS ABOUT 1/4 MI, BUT TO THE WEST, THE VISIBILITY WAS GOOD. THERE WAS ONLY 1 VISUAL POINT ON THE HORIZON. THE PILOT STATED HE BEGAN A CLIMB FOR VISUAL REFERENCE ON THE HORIZON, THEN NOTICED THE HELICOPTER WAS SETTLING. THE ENGINE OUT/LOW RPM AUDIO WARNING & LIGHT ACTIVATED JUST BEFORE THE HELICOPTER IMPACTED SNOW COVERED TERRAIN IN A LEVEL ATTITUDE WHILE MOVING FORWARD. A SKID DUG IN & THE HELICOPTER WENT OVER ON ITS TOP. SUBSEQUENTLY, THE HELICOPTER WAS COVERED WITH SNOW & WAS NOT RECOVERED; THEREFORE, THE CAUSE OF THE APPARENT POWER LOSS WAS NOT DETERMINED. THE ELEVATION OF THE CRASH SITE WAS ABOUT 6800 FT.

- Pilot's situational awareness was apparently degraded as he did not notice that the aircraft was settling, and that the engine had failed until just before impact.
- Possible that the pilot simply flew into the ground due to inadequate vertical rate cues, and the division of attention required to fly in a degraded visual environment in high mountainous terrain.

**850425850425ANC84FA017 CDT**

THE SEARCH & RESCUE FLIGHT HAD BEEN DISPATCHED FROM BARROW TO AN AIRCRAFT ACCIDENT SITE ADJACENT TO THE NUIQSUT AIRPORT. ACCORDING TO THE PILOT, UPON ARRIVING AT NUIQSUT AT 300 FT AGL THE VISIBILITY WAS 2-3 MI. THEY LINED UP WITH SNOW MACHINES FOR A VISUAL APPROACH TO THE SITE & THE CO-PILOT DISENGAGED THE AUTOPILOT FOR DESCENT. THE PILOT IN COMMAND CALLED OUT 200, 100 & 50 FT. AT THE 50 FT CALL-OUT THE AIRCRAFT IMPACTED TERRAIN & BOTH PILOTS PULLED UP ON THE COLLECTIVE. RIGHT AFTER THE PILOT IN COMMAND SAID "WE'RE AT 50 FEET" THE AIRCRAFT AGAIN STRUCK THE GROUND. THE PILOT IN COMMAND WAS GIVING ALTITUDE READOUTS FROM THE RADAR ALTIMETER. THE AIRCRAFT HAD IMPACTED FIRST ON THE EDGE OF A 50 FT GULLY. THE AIRCRAFT HAD APPROACHED OVER THE GULLY. BASED ON OLIKTOK, DEADHORSE & UMIAT WEATHER, THE NUIQSUT AIRPORT WAS ENGULFED IN FOG.

- Altitude and vertical rate cues were apparently very bad (due to fog and snow-covered terrain) as pilots were relying on radar altitude.
- Accident illustrates problems with relying on inside cockpit data during flight in conditions of poor visual cuing.

**860109860109ANC84LA125 MLB**

DURING AN APPROACH FOR LANDING THE AIRCRAFT COLLIDED WITH THE GROUND AND ROLLED OVER. THE PILOT STATED THAT HE FLARED TOO LOW TO THE GROUND AND STRUCK 1 SKID FIRST, LOST DIRECTIONAL CONTROL AND ROLLED OVER.

- Vertical rate and attitude cuing environment was apparently very poor.
- Pilot was apparently not aware of the severity of the degraded cuing; another example of the subtle nature of this problem.

**860218860218ANC85FA036 LDC**

FLIGHT WAS BEING CONDUCTED TO OFF SHORE OIL PLATFORM. PILOT WAS CHECKED OUT FOR OFF SHORE OPERATIONS THE DAY PRIOR TO THIS ACCIDENT. PILOT STATED VISIBILITY ABOVE 500 FT WAS POOR & HE MAINTAINED 500 FT TO STAY BELOW A STRATUS LAYER. ONCE OVER THE WATER THE ONLY VISIBLE HORIZON WAS THE PLATFORM. THE HELICOPTER CONTACTED THE WATER AND ROLLED OVER 1 1/2 MILES OFF SHORE. THE LIFE RAFT WAS SECURED TO THE CHIN BUBBLE AND WAS LOST WHEN THE BUBBLE SEPARATED DURING IMPACT.

- Still another example of the insidious nature of degraded visual cuing during flight with respect to outside references.

**851204851204ATL84FA115 DVT**

THE AIRCRAFT COLLIDED WITH TREES DURING A LANDING AT A COMPANY HELIPAD. THE WEATHER WAS IMC WITH LOW CEILINGS AND FOG. THE AIRCRAFT HAD BEEN CLEARED FOR A VOR APPROACH MONITORED BY RADAR. THE CO-PILOT SPOTTED THE PAD AND CALLED IT OUT TO THE PILOT WHO STARTED A STEEP DESCENT. WHILE COMPLETING THE LANDING CHECK THE CO-PILOT SENSED A NOSE HIGH ATTITUDE OF THE AIRCRAFT AND LOOKED OUT. IT APPEARED THE AIRCRAFT WAS MOVING BACKWARD AND DOWN. HE YELLED "WHERE ARE WE GOING?!" THE CAPTAIN ADDED POWER AS THE AIRCRAFT ENTERED THE TREES. THE NOSE AND RIGHT GEAR COLLAPSED BUT THE AIRCRAFT REMAINED UPRIGHT. THE ROTOR BLADES WERE RUINED BY TREE CONTACT.

**860109860109ATL84FA297 LPW**

WHILE DISMANTLING A WATER TOWER, AN IRON WORKER WAS SERIOUSLY INJURED & PINNED AS HE WAS REMOVING A PORTION OF A WATER TOWER LEG (APPROXIMATELY 92 FT AGL). THE HELICOPTER PILOT RESPONDED TO THE EMERGENCY. THE AIRCRAFT WAS EQUIPPED WITH A MAKE-SHIFT SLING LINE TO RETRIEVE THE INJURED IRON WORKER. THE IRON WORKER DIED, BUT THE HELICOPTER PILOT VOLUNTEERED TO CONTINUE WITH THE MISSION. THE PILOT WAS NOT FAMILIAR WITH THIS TYPE OF OPERATION, BUT A PARAMEDIC WAS ON BOARD TO ASSIST. THE PARAMEDIC WAS NOT FAMILIAR WITH HELICOPTER OPERATIONS. SVR-LQUARTZ HALOGEN LIGHTS WERE USED TO ILLUMINATE THE 4 WATER TOWER LEGS. AT THE PILOT'S REQUEST, ALL BUT 1 WERE TURNED OFF TO KEEP FROM BLINDING THE PILOT AS HE HOVERED OVER THE STRUCTURE AT NIGHT. THERE WAS NO DIRECT RADIO COMMUNICATION BETWEEN THE PILOT & GROUND PERSONNEL, BUT THE PARAMEDIC WAS IN CONTACT WITH GROUND PERSONNEL. WHILE HOVERING, THE HELICOPTER MOVED SLOWLY BACK TOWARD A LEG OF THE STRUCTURE. GROUND PERSONNEL TRIED TO WARN THE PILOT, BUT THE HELICOPTER HIT A WATER TOWER LEG, THEN CRASHED & BURNED.

**8870601870601CHI86FER03 RMM**

THE CFI REPORTED THE ACCIDENT OCCURRED DURING A DEMONSTRATION OF WIND EFFECT DURING TURNS AROUND A POINT. THE CFI REPORTED THAT AS THE HELICOPTER WAS TURNED DOWNWIND IT BEGAN DESCENDING FROM AN ALTITUDE OF APPROXIMATELY 200 FT AGL. IT CONTINUED ITS DESCENT UNTIL THE RIGHT SKID CONTACTED THE TERRAIN AND THE HELICOPTER ROLLED OVER. STRONG, GUSTY WINDS WERE REPORTED AT THE TIME OF THE ACCIDENT.

**870513870513CHI86LA024 LDC**

THE AIRCRAFT WAS DEPARTING THE AIRCRAFT OWNERS BACKYARD AFTER DISCHARGING TWO PASSENGERS. THE PILOT STATED THAT HE WAS EXPERIENCING CYCLIC FEEDBACK AS HE ATTEMPTED TO PICK THE AIRCRAFT UP TO A HOVER. THE FEEDBACK BECAME UNCONTROLLABLE AND THE AIRCRAFT ROLLED OVER. THE TAKEOFF WAS ATTEMPTED FROM WET SLOPING TERRAIN ON A DARK NIGHT WITHOUT THE USE OF A LANDING LIGHT.

- Aircraft inadvertently transitioned to rearward flight, even with two pilots on board. Situational awareness was close to zero for pilot at the controls.
- Horizontal translational rate cues were apparently very poor.
- Division of attention requirements were high as pilots were transitioning from IMC to VMC and completing the landing checklist.

- Undetected rearward drift is a good example of the effect of degraded situational awareness.
- Pilot division of attention was a factor due to complexity of task, lack of familiarity with this type of operation, and the death of one of the workers

- This accident illustrates the significance of turbulence as an element in division of attention from aircraft position. This factor is magnified by the poor flying qualities of unaugmented rotorcraft. That is, they are unstable, and tend to be highly sensitive to gusts.
- Explaining the effect of wind to the student was also an element (divided attention) in the apparent lack of situational awareness of the instructor.

- Aircraft may have been contacting the ground giving the appearance of "cyclic feedback".
- Environmental conditions were highly conducive to degraded visual cuing.
- Poor situational awareness sometimes results in an inability to interpret an otherwise obvious problem.

**860707860707CHI86LA044 VDW**

UPON THE APPROACH TO HOVER FOR LANDING ON A SNOW COVERED AIR STRIP, DRY SNOW BLEW UP AND OBSCURED THE PILOT'S VISUAL REFERENCES. ONE SKID TOUCHED DOWN AS THE HELICOPTER WAS MOVING Laterally CAUSING THE AIRCRAFT TO ROLL OVER ON ITS SIDE.

- Still another example of degraded translational rate cuing due to rotor-induced blowing snow.
- Pilot apparently did not detect the lateral and vertical drift.

**850423850423DEN84LA036 TAG**

THE PILOT REPORTED THAT SNOW HAD BEEN FALLING REGULARLY FOR THE PREVIOUS FEW DAYS BEFORE THE FLIGHT. HE DEPARTED THE STAGING AREA WITH 12 DRILL CREW MEMBERS. AT THAT TIME, THE VISIBILITY WAS 2 TO 3 MI & A CEILING OF 800 TO 1000 FT. THE PILOT FLEW 9 OF THE PASSENGERS TO A SEISMIC LINE ON AN 8000 FT RIDGE LINE, THEN FLEW THE OTHER PASSENGERS TO THE VALLEY FLOOR, WHERE THEIR EQUIPMENT WAS LOCATED. DURING ARRIVAL, THERE WAS A 500 FT CEILING, THE VISIBILITY WAS ABOUT 1 MI & SNOW WAS FALLING LIGHTLY. WHILE LANDING, THE ROTOR WASH KICKED UP CONSIDERABLE SNOW, BUT THE PILOT WAS ABLE TO USE THE DRILL RIGS FOR A VISUAL REFERENCE. HE TOOK OFF AGAIN TO RETURN TO THE STAGING AREA, BUT AFTER FLYING APPROXIMATELY 1/4 MI, THE SNOW SHOWER INCREASED & THE VISIBILITY BEGAN DROPPING. HE DECIDED TO LAND & WAIT FOR THE WEATHER TO IMPROVE. HOWEVER, AS HE APPROACHED THE GROUND, ALL VISUAL REFERENCE WAS LOST DUE TO SNOW KICKED UP FROM THE ROTOR WASH. SUBSEQUENTLY, THE HELICOPTER DRIFTED TO THE RIGHT, THE RIGHT SKID DUG INTO THE SNOW & THE HELICOPTER ROLLED OVER.

- Same comments apply as noted in previous accident.

**851008851008DEN84LA079 DVT**

THE PILOT TOOK OFF FROM A MOUNTAINOUS WORK SITE TO RETURN TO SALT LAKE CITY, UT. THE WEATHER WAS CLEAR AT THE WORK SITE (ELEVATION 6700 FT), BUT THERE WAS FOG BELOW. AFTER ENCOUNTERING THE FOG, THE PILOT HOVERED WITH A SLOW FORWARD SPEED OVER SNOW COVERED TERRAIN. A PASSENGER SAID THAT WHERE ROCKS PROTRUDING THRU THE SNOW, THEY PROVIDED A REFERENCE, THEN SUDDENLY THERE WERE NO ROCKS. AS THE HELICOPTER PROCEEDED OVER AN OPEN AREA, THE PILOT LOST GROUND REFERENCES. HE SAID HE MAY HAVE EXPERIENCED VERTIGO BECAUSE HE THOUGHT HE WAS ABOUT ON THE GROUND WHEN THE HELICOPTER HIT & ROLLED OVER. THE ELEVATION AT THE CRASH SITE WAS ABOUT 5000 FT.

- Poor vertical and horizontal translational rate visual cueing resulted in inadvertent ground contact with lateral drift.
- Pilot was apparently not aware of the loss in cuing until ground contact as he did not pull up.
- Attitude cuing was probably also degraded resulting in sideward flight, and in pilot comment regarding vertigo.

**50713850713FTW84FA107 DVT**

THE PILOTS IN A HELICOPTER ENCOUNTERED FOGGY WEATHER DURING A POSITIONING FLIGHT AND CRASHED INTO A LAKE ABOUT 4 MI FROM THE DEPARTURE POINT. A FISHERMAN WHO WITNESSED THE ACCIDENT SAID THE AIRCRAFT DESCENDED INTO THE WATER IN A NOSE LOW ATTITUDE. THE AIRCRAFT SKIPPED AND TUMBLED FOR ABOUT 100 YARDS BEFORE IT SANK. PILOTS, WHO WERE SEARCHING IN THE AREA SAID THAT THERE WAS A SCUD LAYER BETWEEN 100 & 300 FT AGL. A COUPLE OF AIRCREWS REPORTED THAT SHORTLY AFTER TAKEOFF, THEIR WINDSCREENS FOGGED UP ON BOTH THE INSIDE & OUTSIDE, REDUCING THEIR FORWARD VISIBILITY. ADDITIONALLY, THE PILOTS REPORTED DIFFICULTY MAINTAINING A VISIBLE HORIZON BELOW 300 FT AGL.

- Pilot was apparently unaware that he was decending.
- Attitude cues were apparently also degraded as the aircraft was seen to be nose-low as it impacted the water.
- This accident is a good example of where the ability to safely pull-up and enter IMC conditions would be valuable.

**850713850713FTW84LA116 DVT**

ACCORDING TO THE PILOT, HE TOOK OFF FROM A CAMP SITE TO PICK UP DUCK HUNTERS AT SEVERAL LOCATIONS. DURING THE FLIGHT, HE ENCOUNTERED FOG & TURNED TOWARD VENICE, LA TO LAND. HE THEN SAW AN OIL FIELD STRUCTURE & SOME LAND & ELECTED TO MAKE A PRECAUTIONARY LANDING. WHILE MAKING AN OVER WATER APPROACH, HE WAS LOOKING AT THE OIL FIELD STRUCTURE & THE BANK WHEN THE HELICOPTER TOUCHED DOWN IN THE WATER & ROLLED OVER. THE OCCUPANTS WERE RESCUED BY DUCK HUNTERS IN THE AREA. THE PILOT REPORTED THAT THE VISIBILITY WAS ABOUT 300 FT.

- Flight over water in poor visibility results in a consistently degraded visual environment due to a lack of microtexture.
- The pilot's situational awareness was apparently degraded as he did not detect the sink rate and low altitude.

**850619850619FTW84LA118 DVT**

ABOUT 10 MIN AFTER DEPARTING AN OFFSHORE PLATFORM, THE PILOT ENCOUNTERED AN AREA OF FOG. HE DESCENDED TO APPROXIMATELY 200 FT, SLOWED TO 40 KTS & STARTED TURNING BACK. AS HE WAS TURNING, HE WAS LOOKING TO THE RIGHT TO LOCATE A PETROLEUM PRODUCTION FACILITY TO USE AS A REFERENCE POINT WHEN THE HELICOPTER STRUCK THE WATER & CRASHED. NO SERIOUS INJURIES OCCURRED, BUT RESCUE WAS DELAYED ABOUT 5 HRS DUE TO DETERIORATING WEATHER.

- Same as above .

**850708850708DEN84LA093 DVT**

THE HELICOPTER TOOK OFF IN MARGINAL VMC CONDITIONS AT CLOSE TO CONDITIONS REQUIRING MAXIMUM PERFORMANCE FOR TAKEOFF. THE PILOT ATTEMPTED TO HOVER AT 90 PERCENT RPM WAITING HE SAID "FOR A BREEZE". THE HOVER STIRRED UP SNOW CAUSING A WHITEOUT AND LOSS OF VISUAL CUES. WHEN THE AIRCRAFT WAS SETTTLING THE PILOT APPLIED 100 PERCENT TO CHECK THE DESCENT BUT THE AIRCRAFT STRUCK THE GROUND. AN ARTICLE IN FEB 1984 ISSUE OF FLYING SAFETY HAD SUGGESTIONS FOR THIS TYPE OPERATION WHICH INCLUDES "APPLY SUFFICIENT TORQUE FOR A POSITIVE RATE OF CLIMB

- Degraded vertical rate cues due to snow blown up by rotor.
- Division of attention due to operation near maximum performance limits of the helicopter.

**B860529860529MKC85FCJ01 PSK**

THE AIRCRAFT MADE A HARD OFF AIRPORT LANDING IN AN UNLIGHTED FARM FIELD ON A DARK NIGHT. THE AIRCRAFT "DROPPED IN" FROM ABOUT 50 FT AGL IN A VERTICAL DESCENT. AFTER GROUND CONTACT THE AIRCRAFT ROLLED OVER TO THE RIGHT. NO MECHANICAL MALFUNCTIONS WERE NOTED DURING THE INVESTIGATION.

- Inadequate vertical rate and altitude cues.
- Lack of situational awareness resulted in delayed power correction .

**860812860812MKC86FA020 PSK**

AFTER DEPARTING WEST PLAINS HOSPITAL FOR SPRINGFIELD, TRANSFERRING A CRITICALLY INJURED PATIENT, THE PILOT OF THE EMS HELICOPTER BEGAN TO ENCOUNTER DETERIORATING WEATHER. THE PILOT WAS CONCERNED ABOUT THE CLOSE SPREAD OF TEMPERATURE AND DEW POINT, BUT HAD ADEQUATE CEILINGS AND VISIBILITIES ALONG HIS ROUTE OF FLIGHT TO CONTINUE. AFTER CRESTING A HILL WEST OF MANSFIELD, MISSOURI, ALONG MISSOURI HIGHWAY 60, THE PILOT ENCOUNTERED LOWERING CEILINGS AND LIGHT FOG. THE PILOT STATED HE DID NOT LIKE THE CONDITION OF THE WEATHER AFTER PASSING THE HILL AND INITIATED A RIGHT TURN TO PROCEED BACK TO MANSFIELD. POWER LINES WERE IMPACTED BY THE HELICOPTER IMMEDIATELY AFTER THE PILOT INITIATED THE TURN. THE PILOT DID NOT REALIZE THAT HE HAD DESCENDED LOW ENOUGH TO STRIKE THE POWER LINES THAT WERE OBSCURED IN FOG AND LOW CLOUDS.

- The pilot's situational awareness was degraded by a lack of adequate visual cuing, and by the considerable divided attention requirements of navigating at very low altitude in poor visibility.
- Marginal visual cuing probably existed due to an obscured horizon.
- Attitude stabilization may have decreased the pilot workload for aircraft control to a point where more time could be spent looking for obstacles (see Section 4).



**860722860722MKC86FA037 RMM**

THIS MED-EVAC HELICOPTER WAS BEING POSITIONED TO PICK UP A PATIENT. THE PILOT OBTAINED A WEATHER BRIEFING WHICH INCLUDED A FORECAST FOR A CHANCE OF MARGINAL VMC ALONG THE PLANNED ROUTE, ALTHOUGH AT THE TIME OF THE BRIEFING THE DESTINATION WEATHER WAS VMC. THE FLIGHT DEPARTED AT ABOUT SUNDOWN AND THE DESTINATION WEATHER DETERIORATED WHILE THE FLIGHT WAS ENROUTE. WITNESSES NEAR THE ACCIDENT SITE, WHICH WAS 23 NM SE OF THE DESTINATION. REPORTED FREEZING RAIN AND/OR WET SNOW FALLING AS THE HELICOPTER FLEW PAST THEIR RANCHES AT LOW ALTITUDE HEADING NW. IT WAS COMPLETELY DARK AT THE TIME OF THE ACCIDENT AND THE AREA WHERE THE ACCIDENT OCCURRED IS SPARSELY POPULATED PROVIDING FEW GROUND LIGHTS FOR VISUAL REFERENCE. THE HELICOPTER CRASHED IN HILLY, SNOW COVERED TERRAIN IN A NEAR VERTICAL, NOSE LOW ATTITUDE AND WAS DESTROYED.

**850423850423NYC83AA209 MLB**

WITNESSES OBSERVED THE HELICOPTER FLY ALONG THE BEACH AT ALTITUDE OF ABOUT 100-150 MSL, ENTER A BANK TO THE RIGHT AND DESCEND INTO THE WATER AT AN ANGLE OF ABOUT 45 DEG. EXAMINATION OF THE WRECKAGE FAILED TO REVEAL ANY PRE-IMPACT DISCREPANCIES OF THE AIRCRAFT OR ENGINE.

**860227860227NYC85FA048 LDC**

THE NON-INSTRUMENT RATED PILOT CONTINUED FLIGHT INTO IMC CONDITIONS IN A HELICOPTER WHICH WAS NOT EQUIPPED FOR FLIGHT ON INSTRUMENTS. THERE IS NO RECORD OR WITNESSES OF THE PILOT HAVING RECEIVED A FORMAL WEATHER BRIEFING BUT IT IS REPORTED THAT THE PILOT WAS INFORMED OF FOG MOVING TOWARD AND EVENTUALLY "SOCKING IN" THE AIRPORT. THE PILOT'S REPLY TO THE LAST CALL OF A "SOCKED IN" CONDITION WAS "I HAVE THE AIRPORT IN SIGHT". WITNESSES SAW THE AIRCRAFT HEADING AWAY FROM THE AIRPORT AFTER HAVING HEARD IT FLYING TOWARD THE AIRPORT. THE AIRCRAFT WAS SEEN TO DESCEND AT A STEEP ANGLE TOWARD THE GROUND JUST PRIOR TO IMPACT. THE SIGHTING WAS SHORT (APPROX 3 SECONDS) AND MADE MORE DIFFICULT BY THE REDUCED VISIBILITY DUE TO FOG AND FADING DAYLIGHT (DUSK). INVESTIGATION REVEALED NO MECHANICAL OR PHYSICAL REASONS OF A CONTRIBUTORY NATURE.

**850423850423SEA83FAD02 DVT**

THE PILOT WAS ON A FLIGHT TO DELIVER 3 PASSENGERS & CARGO TO A RIDGE NEAR THE UPPER PART OF A GLACIER. THE ALTITUDE WAS APPROXIMATELY 5200 FT MSL. THE PILOT REPORTED THAT THE WEATHER WAS 6000 FT SCATTERED, VISIBILITY 20 MI, WIND FROM THE EAST AT 5 KTS. ACCORDING TO HIM, HE ENCOUNTERED A WHITE-OUT CONDITION AS THE HELICOPTER WAS ABOUT TO TOUCH DOWN DURING THE LANDING. THE RIGHT FLOAT, THEN THE MAIN ROTOR, STRUCK THE SNOW COVERED SURFACE & THE HELICOPTER ROLLED OVER. THE HELICOPTER WAS SHUT DOWN & ALL OCCUPANTS EVACUATED WITH NO INJURIES. THEY REMAINED AT THE SCENE WITH SURVIVAL GEAR UNTIL RESCUED THE FOLLOWING DAY. THE RESCUE WAS DELAYED BY WEATHER.

- It appears that this pilot encountered IMC conditions and lost control of the helicopter. This situation is distinctly different than the Degraded Visual Environment (DVE) where sufficient terrain features are available to maintain control of the aircraft.
- The ability to safely climb into IMC conditions might have prevented this accident.

- Good Example of how a Degraded Visual Environment can exist in good VMC conditions - quite common for flight over water.

- The pilot seems to have had ground contact since witnesses on the ground could see the helicopter. However, the visual cuing environment was very poor.
- The divided attention workload was also very high as the pilot was attempting to find the airport.
- The combination of a severely Degraded Visual Environment and high divided attention requirements probably exceeded the pilots workload capacity and control was lost.

- The pilot did not detect lateral drift due to the degraded visual conditions over snow.
- Good potential for division of attention due to operation in mountainous terrain, and with a heavy load of passengers and equipment.

**850423850423SEA83LA147 DVT**

THE ROTORCRAFT PITCHED UP, YAWED RIGHT, MADE 180 DEGREE TURN AND LANDED HARD AFTER THE PILOT EXPERIENCED SUN-GLARE DURING INITIAL CLIMB. THE PILOT STATED THAT WHILE DEPARTING THE GRASS STRIP FOR AERIAL APPLICATION, THE SUN BURST FROM BEHIND A CLOUD & BLINDED HIM WHEN HE WAS ABOUT 40 FEET AGL. HE THEN LOST CONTROL OF THE AIRCRAFT AS IT PITCHED AND YAWED AND LOST AIRSPEED. THE PILOT COMPLETED A 180 DEGREE TURN AND LANDED HARD AFTER WHICH THE ROTORCRAFT ROLLED ONTO ITS RIGHT SIDE.

**850423850423SEA84LA025 TAG**

THE HELICOPTER LANDED HARD AND ROLLED OVER TO THE RIGHT. THE EVENTS STARTED WHEN THE PILOT HEARD THE END OF A SEAT BELT BANGING AGAINST THE OUTSIDE OF THE AIRCRAFT WHERE IT HAD BEEN CAUGHT IN THE DOOR. THE PILOT DECIDED TO LAND AND SECURE THE BELT. DURING LANDING THE DOWNWASH FROM THE AIRCRAFT BLEW UP SNOW AND THE PILOT LOST SIGHT OF THE GROUND. A HARD LANDING AND ROLLOVER RESULTED.

**850513850513SEA84LA035 NLH**

THE PILOT STATED, HE WAS ATTEMPTING TO DEPART WITH VISIBILITY OF 1/8 TO 1/4 MI IN FOG. SHORTLY AFTER DEPARTURE THE VISIBILITY DROPPED TO APPROXIMATELY 50 TO 100 FT. HE ATTEMPTED A SLOW RUNNING LANDING AND LANDED HARD.

- Pilot suddenly encountered condition of Degraded Visual Cuing and made inappropriate control inputs that resulted in loss of control.
- Additional stabilization may have assisted the pilot in maintaining control.

- Degraded visual cuing due to rotor-induced blowing snow.
- Divided attention due to seat belt banging on outside of the aircraft.

- Workload to maintain control would be very high in such a degraded visual environment.
- Pilot would have more excess workload capacity to work on sink-rate if rotorcraft were attitude stabilized.

### III DEGRADED VISUAL CUING AS A FACTOR IN ROTORCRAFT HANDLING QUALITIES

#### A Early Ground-Based Simulation Experience

The effects of degraded visual cuing on handling qualities for low speed and hover were first noticed in ground-based simulators. Even though the visual scenes created by camera-model systems and digital image generators seemed to be quite realistic, pilots were unable to accomplish hover performance consistent with flight. In particular, any attempt to be precise and aggressive, resulted in continuous low-to-mid frequency drifting. Example maneuvers that caused problems were precise vertical landings, transitions from forward or sideward flight to a precision hover, and a precise pirouette maneuver around a fixed reference point. These results were consistent for conventional flying helicopters as well as for an ideal K/s (i.e., rate response) controlled element.

The addition of *attitude command augmentation* resulted in a profound improvement in the handling qualities for low speed and hover.<sup>1</sup> In fact, the attitude augmented helicopter on the simulator handled very much like a conventional helicopter in the real world, in terms of the ability to stabilize with respect to outside references.

#### B Initial Flight Tests - What Are the Missing Cues?

A limited flight test program was conducted in the spring of 1984 to investigate the cues required to stabilize the position of a helicopter in the low speed and hover flight regime (see Reference 4). The test vehicle was a Hughes 500D helicopter, and the test site was the Rosamond dry lake at Edwards Air Force Base in California. The dry lake was selected because of its inherent lack of detail. The experimental variables were field-of-view, microtexture, and macrotexture. (i.e., fine-grained detail and large objects respectively). Variations in the field-of-view were accomplished by mounting blackout curtain material on the evaluation pilot's windscreen with various cutouts tailored to represent the simulators at NASA Ames Research Center. A smaller cutout was used to represent a typical forward looking infrared (FLIR) monitor, and the other extreme of no curtain at all was tested as a baseline case. The fine-grained or "microtexture" was varied by using goggles that could be electronically fogged just enough to remove the pilot's ability to see small cracks in the lake-bed, but to still see all large objects in the field-of-view. Variations in macrotexture were accomplished by using two test sites on the lake-bed; one with considerable detail (consisting of tires, posts, and lines painted on the surface), and the other with just enough detail to accomplish the assigned tasks.

The experimental data consisted of subjective pilot ratings using the standard Cooper Harper Handling Qualities Rating (HQR) Scale, which is shown in Figure 1, and a "Visual Cue Rating (VCR) Scale." This scale was developed to quantify the ability of the pilot to use attitude and translational rate cues for stabilization. The original version of this scale included descriptors that attempted to quantify the pilot's ability to perceive the necessary cues for attitude and

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<sup>1</sup> In this report, attitude command augmentation refers to dynamics such that a constant force or displacement of the longitudinal or lateral cyclic results in a constant pitch or roll attitude. Letting go of the cyclic results in the aircraft returning to its trim attitude.

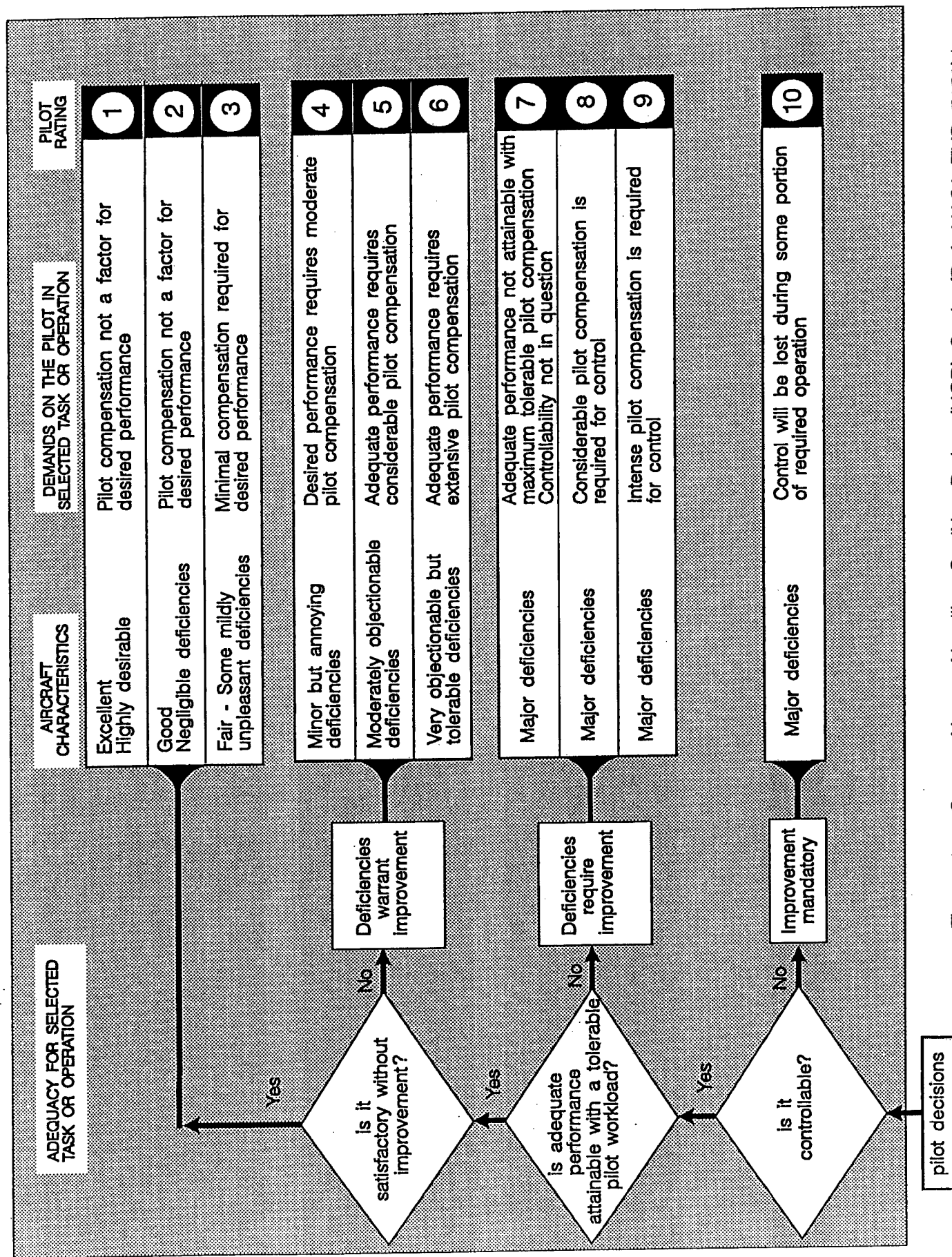
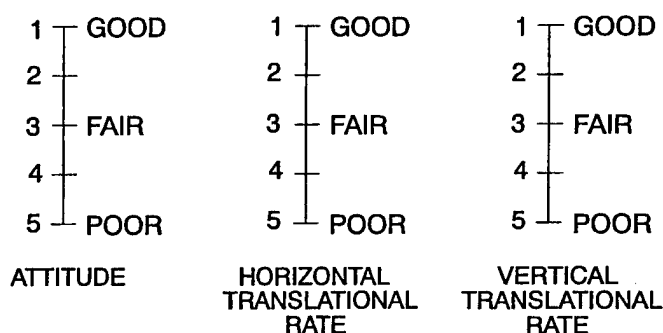


Figure 1. Cooper Harper Handling Qualities Rating (HQR) Scale (Ref. NASA TND 5153)

translational rates, and is shown in Figure 2. Experience with the original VCR scale indicated that pilots are not able to reliably rate the quality of the visual cues. For example, visual cue environments that looked completely adequate before liftoff turned out to be very difficult to cope with once airborne. The final visual cue rating scale, which is used in the current version of the military rotorcraft flying qualities specification (ADS-33C, see Reference 3), makes no reference to the pilot's perception of the cuing environment. This scale relies completely on the pilot's ability to be aggressive and precise (see Figure 2). In briefing pilots to use this scale, it is explained that the term "aggressive" refers to "hummingbird-like agility" and not to large angular rates and attitudes. For example, it should be possible to transition from a low speed hover-taxi to a precision hover without significant transient motions if a Visual Cue Rating (VCR) between 1 and 2 (i.e., good cues) is issued from the Figure 2 scale.



### DEFINITIONS OF CUES

X = Pitch or roll attitude and lateral, longitudinal, or vertical translational rate.

#### Current Definitions (Used in Reference 3)

Good X Cues: Can make limited X corrections with confidence and precision is good

Fair X Cues: Can make limited X corrections with confidence and precision is only fair.

Poor X Cues: Only small and gentle corrections in X are possible, and consistent precision is not attainable.

#### Original Definitions (Used in Reference 4)

Good X Cues are easily and quickly perceived allowing pilot to make aggressive corrections with confidence.

Fair X Cues require considerable concentration to perceive accurately, allowing pilot to make only moderate corrections or changes with confidence.

Poor X Cues require full concentration to perceive enough information for aircraft control. Only small and gentle corrections are possible, and consistent precision is not attainable.

Figure 2 Comparison of Original and Current Visual Cue Rating (VCR) Scale Definitions

The details of the first visual cueing experiment are described in References 4 and 5. The results of the testing are summarized in Figure 3 in terms of the Cooper-Harper Handling Qualities Ratings (HQRs) and Visual Cue Ratings (VCRs). These data indicate that with the fine-grained texture fogged out, increasing the field-of-view did not result in a significant improvement in the subjective pilot ratings (HQRs and VCRs). The data in Figure 3 are for the test course with considerable macrotexture (i.e., many large objects). However, the data for the test course with essentially no macrotexture (an "L" painted on the lake-bed) are essentially identical. This indicates that the primary cue for stabilization in the low speed and hover flight regime is microtexture. This result suggests that problems with controllability are to be expected in visual environments where the microtexture cue is minimal or completely lacking. Some examples are:

- Flight over snow covered terrain, especially when the snow is blown up around the helicopter by the rotor wash.
- Flight over water at very low altitudes
- Any low altitude flying at night, especially without a landing light
- Flight with night vision goggles or forward looking infrared (FLIR) — experience has shown that both of these displays suffer from a lack of microtexture in critical conditions (i.e., very low light levels, and after a cold soak).

The first three examples are based on the accident summaries in Section 2, whereas the last is a result of the engineering flight-testing and research conducted in support of the military flying qualities specification. (see Reference 5).

### **C Variable Stability Helicopter Flight Testing - Can Added Stabilization Compensate for Missing Visual Cues?**

The first visual cueing experiment (Reference 4) was accomplished with a standard Hughes 500D helicopter, and therefore the flying qualities were conventional. All five pilots agreed that the basic handling qualities were consistent with HQRs of 3 or better when flying in conditions of good visual cueing (i.e., without the fogged goggles and restricted field-of-view). As shown in Figure 3, degrading the visual conditions resulted in a deterioration in the handling qualities ratings. Pilots who had flown ground-based rotorcraft simulations indicated that the controllability problems encountered there were similar to those experienced in flight in the degraded visual environment. Follow-on testing was conducted using a variable stability Bell 205A helicopter at the National Research Council of Canada (NRC). The purpose of this testing was to determine if adding attitude stabilization would compensate for degraded visual cueing in the flight environment, in a similar manner to the improvements noted on the ground-based simulators. The data from that experiment is plotted in Figure 4a for a conventional or rate responding helicopter, and in Figure 4b for an attitude augmented helicopter. A linear regression analysis was accomplished using the variable stability data for Rate Response-Types, as well as the data from the first experiment at Edwards AFB. This resulted in the following expression, which relates the deterioration in handling qualities (HQRs) to the degradation in visual cueing (VCRs).

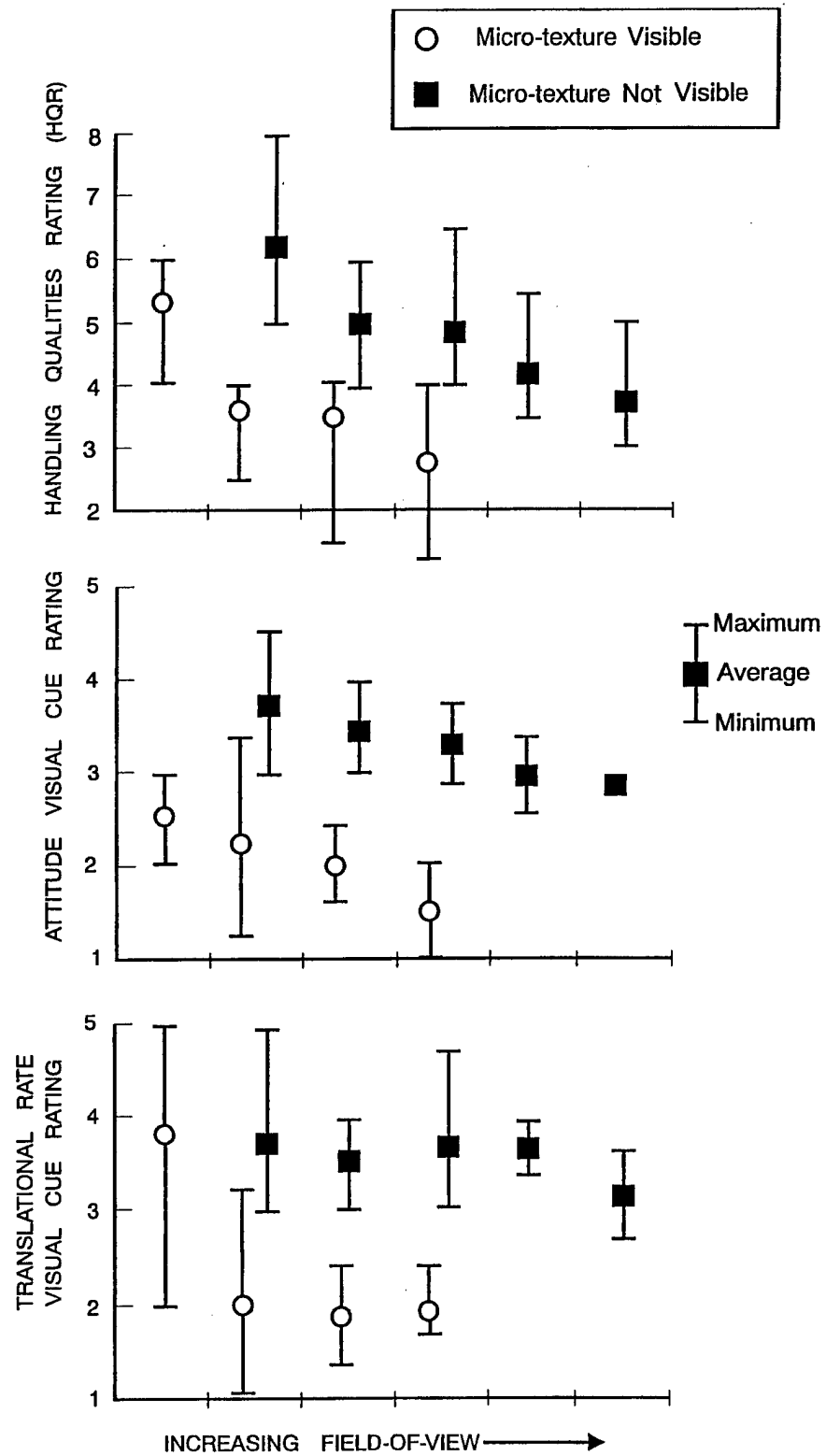


Figure 3 Effect of Variations in Field-of-View

$$HQR = 0.89 + 0.89VCR_{\theta} + 0.60VCR_x \quad (3-1)$$

This expression was used to divide the data into three regions of handling qualities as shown by the dashed lines in Figure 4a. These lines are superimposed on Figure 4b where the HQR data for the configurations with attitude command augmentation is plotted. For the most part, the region that contained handling qualities ratings (HQRs) between 3.5 and 5.5 for the Rate Response-Types, now contain HQRs that are equal to or better than 3. (Most cases rated as 4 were flown in turbulent conditions (flagged points)). *These data indicate that the addition of attitude command augmentation results in a substantial improvement in handling qualities in a degraded visual environment (DVE).*

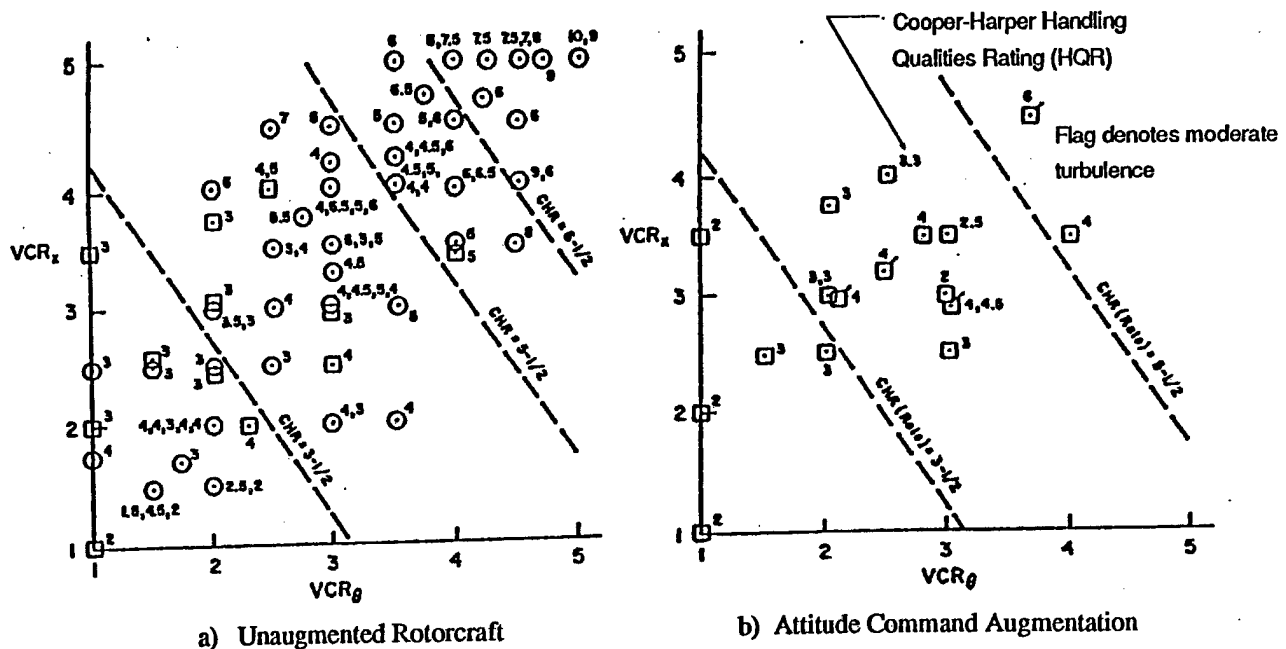


Figure 4 Effect of Attitude Command Augmentation on Handling Qualities

In summary, the above described flight test experiments have resulted in two important conclusions regarding low speed and hover flight in a degraded visual environment.

- Degraded visual cueing, due to a loss of the ability to perceive microtexture, results in a deterioration in flying qualities for unaugmented helicopters.
- The use of attitude stabilization significantly reduces the deterioration in rotorcraft flying qualities in degraded visual environments.

Additional flight testing with the NRC variable stability Bell 205A further verified and expanded the scope of these results. The data from these tests are plotted in Figure 5. They indicate a clear trend toward improved handling qualities with the addition of stability augmentation. Vertical-rate-command with height-hold (RCHH) is seen to be a desirable



addition to attitude command attitude hold (ACAH). This is consistent with the accidents in Section 2 where excessive vertical rates and a loss of altitude awareness were primary factors. The average rating for the translational rate command in UCE = 2 is 2.5, but there are some excursions to HQR = 4. These were primarily due to hardware problems, which have since been resolved (TRC augmentation is described in detail in Reference 6). Finally, the Figure 5 data indicate that in severely degraded visual cueing (UCE = 3; solid data points in Figure 5), the HQRs range from 5 to 7.5 for a helicopter with only rate augmentation. A review of the Figure 1 HQR scale shows that such ratings are indicative of very poor handling qualities. The ratings for attitude command and translational rate command show some improvement in the UCE = 3 handling qualities, but not to the extent seen in UCE = 2.

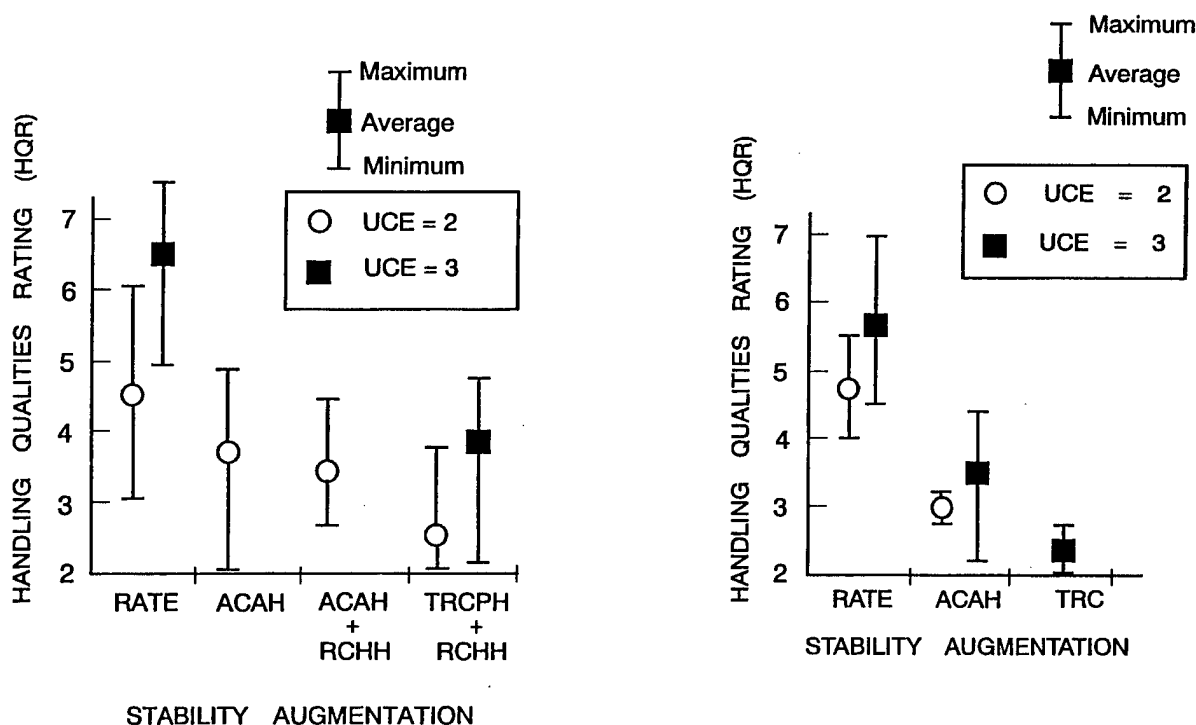


Figure 5 Handling Qualities Rating Data From In-Flight Simulation in a Degraded Visual Environment

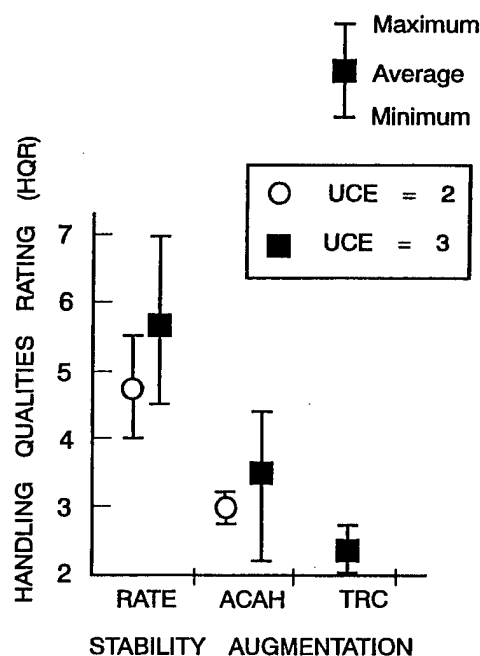


Figure 6 Handling Qualities Rating Data From Ground-Based Simulation (See Appendix B for abbreviations)

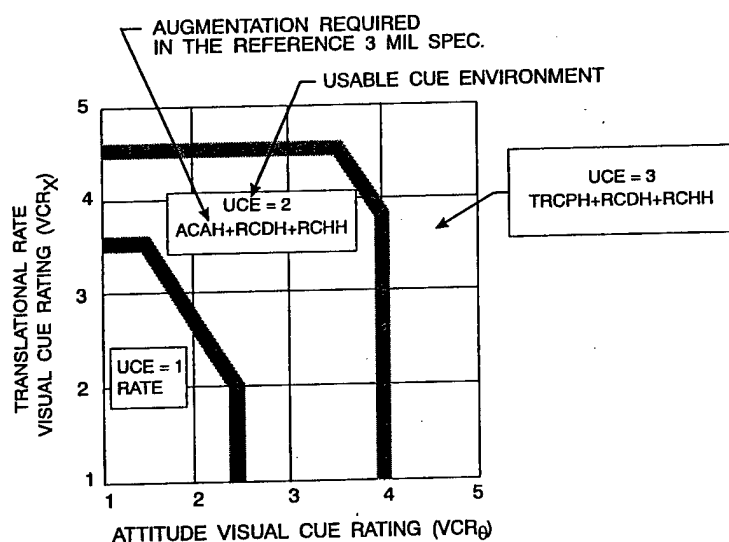
A ground-based simulation was conducted (by the U.S. Army Aeroflightdynamics Directorate) at the NASA Ames Research Center, using the Vertical Motion Simulator, to further investigate the effects of degraded visual cueing. These results are summarized in Figure 6, where the pilot rating trends are seen to be in good agreement with the flight-test data in Figure 5. The

ground-based simulation data indicate significantly less pilot rating spread for ACAH in UCE=2 and TRC in UCE=3. This is probably due to the ideal augmentation that can be obtained in a ground-based simulator. It illustrates that high quality augmentation is required to accomplish improved handling qualities in the DVE. Design criteria for attitude and translational rate command augmentation are given in the Reference 3 handling qualities specification.

The data in Figures 4, 5, and 6 lends considerable insight to the accident briefs in Section 2. They show that the pilot ratings for a Rate Response-Type (i.e., a conventional helicopter) range from 3 to 7 for UCE = 2 and from 4.5 to 10 for UCE = 3. Some of the flight conditions described in the accident briefs (Section 2) were almost certainly solid UCE = 2, and may have been UCE = 3. It will be shown in the following section that these degraded Qualities result in very high pilot workload. Such high workload for aircraft control cuts significantly into the pilot's excess capacity for situational awareness.

#### D The Usable Cue Environment (UCE)

The relationship between visual cue ratings, UCE, and augmentation used in the Reference 3 specification is summarized in the plot in Figure 7. These boundaries were derived from the data in Figures 4, 5 and 6. Such boundaries would be overly restrictive for civilian operations.



Nonetheless, they provide valuable guidance as to the type of augmentation that is required to provide ideal handling qualities in conditions of increasingly degraded visual cuing. A less rigorous interpretation of the UCE is given below.

Figure 7 Definition of UCE from Reference 3

- UCE = 1 implies that the averaged  $HQR \leq 3.5$  for a conventional helicopter with good flying qualities.
- UCE = 2 implies that the  $HQR$  is between 3.5 and 5.5 for a conventional flying helicopter, or  $HQR \leq 3.5$  for a helicopter with attitude augmentation and rate command height hold (RCHH).
- UCE = 3 implies that the  $HQR \geq 5.5$  for a conventional helicopter or 3.5 for a helicopter with TRC augmentation and with rate command height hold.

In terms of guidance for civilian rotorcraft, the data indicates that the addition of attitude command and rate command height hold augmentation would be highly beneficial for improved handling qualities in degraded visual environments. For rotorcraft that will operate in more severe DVEs, a translational rate command augmentation would be recommended. For example, this would apply to operations over water, or snow, especially if conducted in poor weather and at night. It will be shown in the following section that improved handling has a direct and positive impact on pilot workload and situational awareness.

#### **IV PILOT WORKLOAD, A FUNDAMENTAL FACTOR IN OBSTRUCTION AVOIDANCE**

##### **A Defining and Measuring Workload**

A wide variety of methods exist to measure pilot workload, all of which have their strengths and weaknesses (e.g., see Reference 7 for a general overview). The nature of workload is such that none of the measures are highly precise and repeatable. However, human factors researchers have developed models that can predict trends and limiting conditions. For example, experiments have shown that the ability of the human operator to attend to several sources of information simultaneously is severely restricted (e.g., References 8 and 9). According to currently accepted human workload theory, a pilot who must process information that exceeds his workload capacity will be highly prone to committing errors.

The basic premise of this study is that many of the accidents reviewed in Section 2 were the result of an overloaded pilot. We assert that this was a result of excessively high workload requirements for rotorcraft control in the degraded visual environment. Since the pilot's total workload capacity is fixed, the effort used for aircraft control must be diverted away from maintaining situational awareness. In this section, a method is developed to quantify the attentional demand required to control the rotorcraft as a function of the visual cueing environment, the turbulence environment, and flying qualities. As the value of attentional demand (AD) for rotorcraft control approaches 100%, the excess workload capacity (EWC) to maintain situational awareness approaches zero ( $EWC = 1 - AD$ ). This scenario results in piloting errors that are often totally out of context with the pilot's known ability and experience level (e.g., many of the accident briefs in Section 2).

##### **B Quantification of Workload in Terms of Cooper-Harper Handling Qualities Rating**

The attentional demand required to control an aircraft can be approximated from the data developed in Reference 10. Here it is noted that subjective Cooper-Harper Handling Qualities Ratings (HQRs) have significant workload connotations, and can be related to the required attentional demand (AD) and excess workload capacity ( $1-AD$ ) for the task of controlling the aircraft. The attentional demand required for aircraft control was experimentally obtained as a function of HQR in Reference 10, and is further discussed in References 11 and 12. This multi-axis piloted simulation experiment used a technique referred to as the "cross-coupled subcritical task." The primary task was to track a sum of sine waves in the pitch axis, in the presence of a secondary roll task. The roll axis was mechanized as a first-order unstable element ( $s - \lambda_2$ ), where the value of  $\lambda_2$  depended on the error in the primary pitch axis. The experiment was set up so that when the pitch axis error was large, the secondary instability was

small (i.e.,  $\lambda_s$  small), and when the pitch axis error was small, the instability was larger (i.e., larger values of  $\lambda_s$ ). During the initial tracking efforts, the pilot varied his pitch control aggressiveness. Excessively tight tracking in the pitch axis resulted in an uncontrollable instability in roll, causing the pilot to back-off in pitch. After a period of tracking, the pilot tended to settle on a steady value of  $\lambda_s$  and therefore a steady value of root-mean-square pitch attitude tracking error. The instructions to the subject pilot in the Reference 10 and 11 tests were as follows. "Your objective is to get the highest secondary task score you can. To get a high score you must keep the primary task error very small. If you allow the primary error to get large, your score will decrease. The problem will stop if either primary or secondary tasks are allowed to exceed the display limits." A block diagram of both primary and secondary tasks is shown in Figure 8.

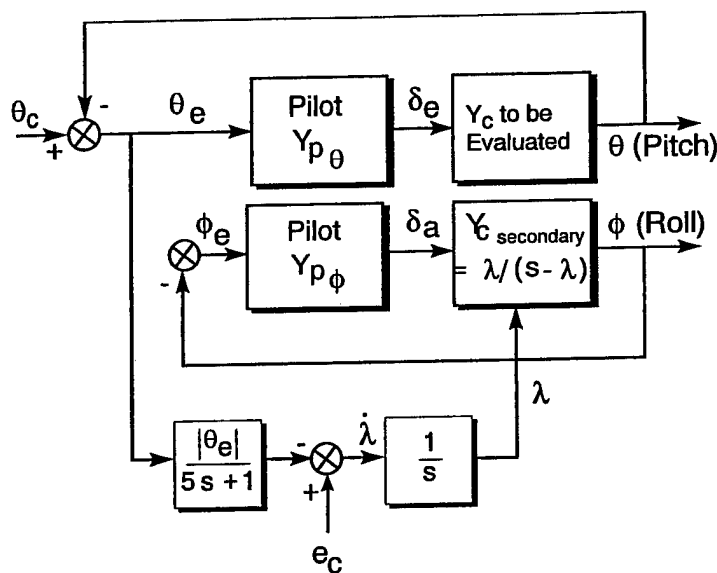


Figure 8 Block Diagram of Cross-Coupled Subcritical Task

The steady value of the instability that was achieved depended on the difficulty of the primary pitch axis task. For example, if the pitch axis dynamics,  $Y_c$ , were easily controlled, the pilots spent most of their time on the unstable roll axis. This would allow them to achieve a large steady value of  $\lambda_s$ , and small values of the pitch attitude tracking error. Conversely, if the pitch axis dynamics were difficult to control, it was not possible to devote much attention to the secondary roll axis. In such cases, the subjects soon found out that it was necessary to back off on the aggressiveness of the pitch tracking (i.e., accept larger pitch attitude error) and

consequently lower values of secondary axis instability,  $\lambda_s^1$ . The experimental scenario in Reference 10 was as follows.

<sup>1</sup> The details of the divided attention subcritical task experiment are somewhat complex and are not required to understand the concepts in this report. It should be noted however, that some attempts to reproduce the results from Reference 10 have been only partially successful (discussed in more detail in Appendix A). Because of the highly useful nature of the experimental connection between handling qualities and workload, it would be desirable to conduct this experiment using a modern simulation facility. The workload values quoted herein must be considered as trends until such additional data are obtained.

- The pilot first performed the primary pitch axis task alone and assigned an HQR. This was done for controlled elements that ranged from a pure integrator (K/s) to a first order instability (i.e., from very good to very bad). The criterion values for calculating  $\dot{\lambda}$  ( $e_e$ , and  $|\theta_e|$  in Figure 8) were based on a multiple of the root mean square pitch attitude error from this run (a factor of 1.2 was used in Reference 10).
- At the beginning and end of each day, calibration runs were made by allowing the pilot to fly the secondary roll axis task alone to determine the maximum achievable value of  $\lambda$  attainable under full attention conditions. The value of the unstable root that could be achieved is termed  $\lambda_c$  or the “critical task score”.
- The pilot flew a range of primary axis controlled elements ( $Y_c$  in Figure 8) in the presence of the secondary task, resulting in a final “score”  $\lambda_s$ , for each  $Y_c$ .

The value of  $\lambda_s$  that could be achieved depended, to some extent, on the motor skill of the test subject. The secondary task scores ( $\lambda_s$ ) were normalized by  $\lambda_c$  to remove this effect. Note that this is equivalent to noting that each individual reaches 100% workload capacity at a unique level of task-loading, depending on their motor skills and experience. For the task of controlling the helicopter, the attentional demand and excess workload capacity are expressed as follows.

$$\text{Attentional Demand (AD)} = (1 - \frac{\lambda_s}{\lambda_c})$$

$$\text{Excess Workload Capacity (EWC)} = (1 - \text{AD}) = \frac{\lambda_s}{\lambda_c}$$

The results of the Reference 10 experiment are summarized in Figure 9, which represents a quantification of pilot workload (attentional demand) in terms of the handling qualities (HQR) of the aircraft.

### C Estimates of Pilot Workload

Nearly all the accident summaries in Section 2 were selected from the NTSB data on the basis that they occurred in conditions of degraded visual cueing. It is suggested that a level of workload higher than might be intuitively estimated was a primary cause of these accidents. That is, the workload may have exceeded 100% of the average competent pilot's total capability. Numerical approximations to the pilot workload associated with the accident scenarios that are presented in Section 2 are developed in this section. This is accomplished by using the concepts developed in Section 3 and the relationship between workload and handling qualities in Figure 9.

Figure 9 represents an experimentally derived relationship between pilot workload (attentional demand), and the vehicle handling qualities as expressed in terms of subjective pilot ratings (HQRs). For example, if the handling qualities of a rotorcraft are represented by  $\text{HQR} = 3.5$ , control of the aircraft is predicted to require approximately 30% of the pilot's workload capacity

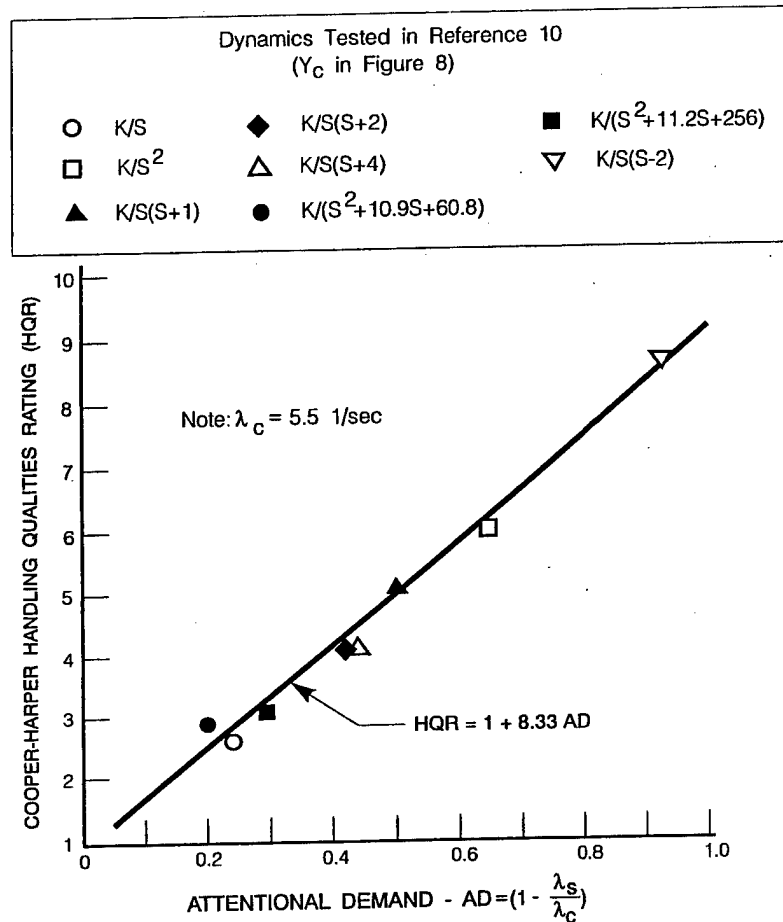


Figure 9 Experimental Correlation Between Handling Qualities and Pilot Workload

(i.e.,  $AD = .30$  from Figure 9). The excess workload capacity to perform other tasks (such as situational awareness) would therefore be 70% of the pilot's workload capacity ( $EWC = .70$ ). If the flying qualities are degraded so that the HQR is 6.5, the predicted attentional demand, simply to control the rotorcraft, increases to nearly 70% of the pilot's total capacity (i.e.,  $AD = .70$  in Figure 9). This leaves only 30% to accomplish procedural tasks and to maintain situational awareness. The accident summaries in Section 2 indicate that typical degradations in visual cueing result from flight over non-textured areas such as snow, water, or grassy areas at night. This would correspond to visual cue ratings of "fair to poor" (i.e., VCRs between 3 and 5 on the Figure 2 scales), based on the testing in Reference 5. Using the regression formula for HQR as a function of VCR (equation 3-1), and the straight-line data fairing in Figure 9, the attentional demand can be calculated as a function of the visual cueing as follows.

$$AD = -0.013 + 0.107VCR_\theta + 0.072VCR_x \quad (4-1)$$

The context of this expression is that it is only an approximation, and represents empirically derived trends. Nonetheless, it is extremely valuable as it allows us to gain an appreciation of the

order of magnitude of attentional demand as a function of visual cueing, basic rotorcraft handling, and atmospheric disturbances. To obtain some appreciation for the effects of the variations in each of these factors, assume that the attitude and translational rate cues degrade together (i.e., that  $VCR_0 = VCR_x = VCR$ ). Equation 4-1 then becomes:

$$AD = -0.013 + 0.18 VCR \quad (4-2)$$

As an example, this expression tells us that if the visual cues are fair-to-poor ( $VCR = 4$ ), the corresponding attentional workload demand is predicted to be 71%. This is just to control the helicopter, and it assumes good basic handling characteristics and calm air. It is notable that a number of the accidents in Section 2 included winds and turbulence in addition to degraded visual cueing. Experience has shown that turbulence causes a degradation in the handling qualities, which is quantified as an increase in the HQR. Reference 13 indicates that, for moderate turbulence, an increase of approximately 2 HQR rating points would be expected over calm air conditions. Assuming that this increment in HQR is representative, the expression for attentional demand in moderate turbulence is:

$$AD = 0.23 + 0.18 VCR \quad (4-3).$$

If we extend the example to include conditions of moderate turbulence (i.e., using equation 4-3), the attentional workload demand is predicted to be 95%. This is based on a rotorcraft with very good basic handling (note that the equation 3-1 regression formula yields an HQR of 2.4 for ideal visual cueing, i.e.,  $VCR = 1$ ). Many civilian rotorcraft do not have ideal handling qualities in the low speed and hover flight regime. Assuming a more typical HQR of 4.5, the formulas for attentional demand with and without turbulence are given as follows:

$$AD = 0.24 + 0.18 VCR \quad \text{No turbulence} \quad (4-4)$$

$$AD = 0.48 + 0.18 VCR \quad \text{Moderate Turbulence} \quad (4-5)$$

For a rotorcraft with only fair handling qualities, in conditions of fair-to-poor visual cueing, and moderate turbulence (i.e., equation 4-5), the attentional demand requirement (to just control the helicopter) is estimated to be 120% of the pilot's capacity. This clearly leaves no time to maintain situational awareness.

The trends predicted by the above expressions are plotted in Figure 10. The effect of an attitude command attitude hold augmenter (ACAH) has been included on this plot, based on the pilot ratings in Figure 4b, and using the linear regression formula in Figure 9. The data in Figure 4b indicate that the HQRs remain nearly constant with increasing VCR until the VCRs exceed about 3.8. In addition, the HQRs for ACAH do not exceed 5 in  $UCE = 3$  (Figure 6). This translates to an attentional demand of 0.48 from the regression formula in Figure 9. The following interpretations and observations can be made from the trends shown in Figure 10.

- The pilot workload for control of the rotorcraft can easily approach or even exceed 100% in a degraded visual environment (DVE). This is for a rotorcraft without augmentation (solid lines in Figure 10).

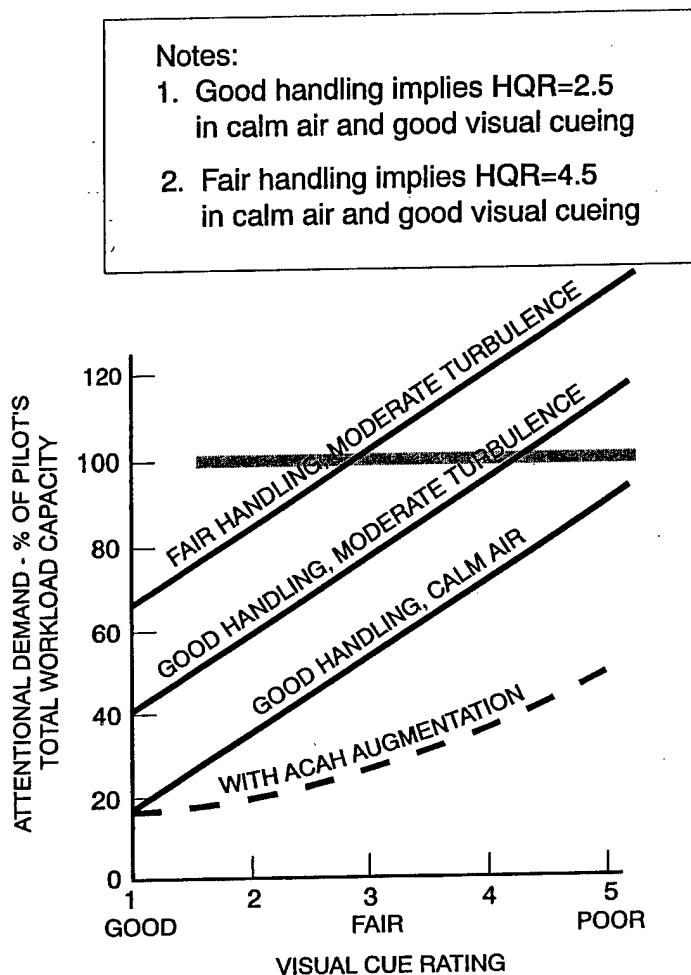


Figure 10 Predicted Increase in Attentional Demand Requirements Due to Degraded Visual Cueing.

- Atmospheric turbulence, combined with the only fair handling qualities of most current rotorcraft, combine to increase workload for control to 100% for even moderate degradations in visual cueing.
- The very high levels of pilot workload for rotorcraft control in the DVE result in a high probability of pilot error. When this error takes the form of poor situational awareness, collisions with obstructions or the ground are likely.
- Adding ACAH and RCHH stability augmentation significantly reduces the pilot workload for control of the rotorcraft in the DVE (see dashed line in Figure 10). This results in increased excess workload capacity, and hence improved situational awareness

The connection between attentional demand requirements and an accident is not well defined, and exceedances of 100% certainly do not guarantee an accident.

However, it is intuitively obvious that the probability of a serious mistake is much higher when the workload approaches or exceeds 100%. The accidents in Section 2 probably represent the unfortunate circumstance where a serious error occurred in near proximity to an obstacle or the ground (or water). Based on the above workload estimates, the operation of an unaugmented helicopter in conditions of degraded visual cueing is a high-risk venture, and the number of "close calls" probably far exceeds the number of accidents.

The data and calculations presented in this section indicate that ACAH and RCHH augmentation can play an important role in improving situational awareness in degraded visual environments



(DVEs)<sup>1</sup>. The value of stabilization in DVEs is well recognized by the U.S. Navy, which requires at least attitude augmentation for over-water operations close to the surface. It is important that any such augmentation be properly implemented to assure that the potential benefits are realized. The U.S. Army military flying qualities specification for rotorcraft (ADS-33C, Reference 3) presents criteria for attitude command systems. It is also important that most of the other criteria in this specification be satisfied to achieve the good handling qualities required for safe flight in the DVE. Providing a good attitude command augmentation system would be of little value if other significant handling deficiencies existed, e.g., excessive inter-axis coupling.

## V. CONCLUSIONS

It is not intuitively obvious why increased stabilization should have an effect on the probability of inadvertent collisions with obstructions, or the ground, in conditions of degraded visual cueing. However, the visual cueing tests described in Section 3 and the pilot workload analysis of Section 4 indicate that additional stabilization can indeed be expected to have a significant positive impact on safety. The findings that support this assertion are summarized below.

- Low speed and hover operations in a degraded visual environment result in a degradation in the effective rotorcraft handling qualities. This occurs due to a loss in the ability of the pilot to adequately perceive fine-grained texture in the field-of-view.
- The degraded handling qualities result in a substantial increase in pilot workload simply to control the helicopter. This leaves very little excess workload capacity to maintain adequate situational awareness (i.e., awareness of distances and rates with respect to obstacles and the ground).
- The addition of turbulence and winds, as well as procedural task loading factors (observe torque, tune radios, etc.) further increases the pilot workload.
- As a result of the above factors, the total workload can easily exceed 100% of the pilot's capacity, a situation which significantly increases the probability for a serious error.
- Increased stabilization has a substantial positive effect on reducing pilot workload in conditions of degraded visual cueing. This effect is not well understood in the helicopter community, and is similar to the concept of using autopilots in fixed-wing aircraft 20 years ago. (The safety benefits of an autopilot for IMC flight were not well understood and there were a significant number of accidents from loss of control).

It is suggested that a pilot education program be undertaken to improve awareness of the danger of low speed and hover operations in areas of minimal visual cueing (even though it is legal), and

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<sup>1</sup> It is not currently clear as to the relative importance of ACAH and RCHH. Based on results of the early testing, it appears that a significant improvement in handling qualities can be achieved with just ACAH. However, it was found that RCHH is required to achieve flying qualities that were "satisfactory without improvement" in the DVE. Since this is required by the military specifications (i.e., Level 1, see Reference 3), RCHH was included as part of the ACAH augmentation in the experiments.

encouraged to provide attitude stabilization as an option for aircraft that will be used in conditions of degraded visual cueing (e.g., search and rescue, oil rigs, snow covered terrain, emergency medical services, etc.).

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## APPENDIX A CAVEATS REGARDING THE CROSS-COUPLED SUBCRITICAL TASK

The details of the divided attention cross-coupled subcritical task experiment are somewhat complex, and are not required to understand the concepts in this report. This appendix has been included to allow the more technically oriented reader to evaluate the accuracy and context of the numerical approximations of pilot attentional demand in Section 4.

An attempt was made to repeat the Reference 10 results in Reference 11. These later results are superimposed on the Reference 10 data in Figure A-1. The data are in reasonable agreement for the more difficult case (i.e.,  $K/s^2$ ). There is, however, a significant shift towards higher attentional demand for the  $K/s$  case. This is explained in Reference 11 to be a result of an increase in the input level for the easier controlled elements (input level was held constant in Reference 10). However, a more recent attempt to repeat the Reference 10 results (unpublished) tends to agree with Reference 11, and the input level was held fixed. Fortunately, the primary area of concern is for the easy controlled element ( $K/s$ ). The conclusions of this study are based on the results for the more difficult controlled elements (e.g.,  $K/s^2$ ,  $K/(s(s+1))$ , etc.) where attentional demand is high.

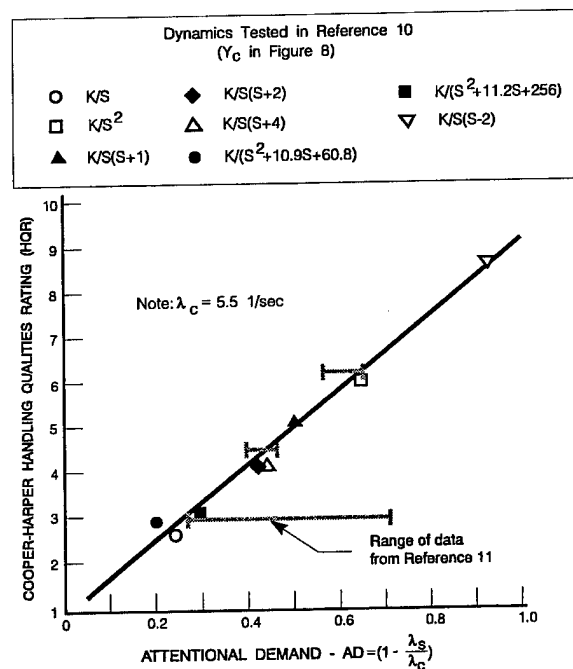


Figure A-1 Addition of Reference 11 Data on Cross-Coupled Subcritical Task Results

One explanation for the unexpectedly high values of AD for the easier controlled elements (i.e., for HQR 3) is that the pilots probably do not work proportionally harder on the primary task

when it is easier. Since  $\lambda_s$  is proportional to the primary axis error, it reflects the pilots' tendency to "back off" as a lower steady value. It is important to note that the full attention value of  $\lambda$  (i.e.,  $\lambda = \lambda_c$ ) tended to be constant at approximately 5.5 1/sec for all experiments. This means that the normalizing factor used for full attention tracking is generally valid.

In addition to the details of the data correlations, there is a question of applicability that should be addressed. The cross-coupled subcritical task experimental scenario involves tracking a single display that has two axes of control (pitch and roll). This type of divided attention activity is undoubtedly different from tracking several displays, or attending to procedural tasks in addition to aircraft control. However, until data becomes available for these latter types of divided attention, we are operating under the assumption that the orders of magnitude and trends are correct. Indeed, the conclusions reached do not depend on exact values of attentional demand, but more on the trend towards significantly higher workload with degraded environmental conditions and basic vehicle handling. The drastic reduction in workload with added stabilization is also based on trends as well as actual observations from flight tests and ground-based simulation.

## APPENDIX B LIST OF SYMBOLS AND ABBREVIATIONS

ACAH	Attitude-Command-Attitude-Hold augmentation
AD	Attentional demand. In this report AD refers to workload required to control the aircraft.
DVE	Degraded visual environment
EWC	Excess workload capacity. Refers to workload capacity for piloting functions other than aircraft control.
HQR	Cooper-Harper handling qualities rating
NTSB	National Transportation Safety Board
RCHH	Rate-command-altitude (height) hold augmentation
RCDH	Rate command direction (heading) hold augmentation
s	Laplace operator (1/sec)
TRC	Translational rate command augmentation
TRCPH	Translational rate command augmentation with position hold
UCE	Useable cue environment (see Figure 7)
VCR	Visual cue rating (Figure 2)
$\lambda$	Value of unstable root in cross-coupled subcritical task (Figure 9)
$\lambda_s$	Value of $\lambda$ when it is the unstable root in a secondary task
$\lambda_c$	Value of $\lambda$ when it is the unstable root in a single axis task
$\theta$	Pitch attitude
$\phi$	Roll attitude